Hilgard, E. W.

On the geology of the delta

ON THE

GEOLOGY OF THE DELTA,

AND THE

MUDLUMPS OF THE PASSES OF THE MISSISSIPPI.

By EUG. W. HILGARD.

[Read before the American Association at its last meeting in Troy.]

[From the American Journal of Science and Arts, Vol I, 1871.]

In previous papers* read before this Association, I have communicated the results obtained during two successive geological expeditions to Louisiana, so far as the more ancient formations are concerned. It is the object of the present communication to present and discuss the phenomena of that portion of the territory explored by me, lying within what is usually considered the alluvial area, proper or Delta, of the Mississippi river. Most of these observations were made in 1867, during the first of these excursions referred to, under the auspices of the Smithsonian Institution; their publication having been delayed in consequence of want of time, on my part to carry out the large amount of chemical and microscopic work involved in the discussion, which is even yet far from being as full as would be desirable. I hope, however, to be enabled, hereafter, to continue the investigation of the subject, both in the field and in the laboratory.†

I. *The Upper Delta Plain.*

I recall to mind the fact that, as we descend the Mississippi, the older strata successively sink from view. A few miles below Vicksburg we lose sight of the older Tertiary. Thence down to the latitude of Tunica Bend, La., we find the rocks of the Grand Gulf (Tertiary) age, possessing but a very faint southward dip. Next, the oldest representative of the quaternary epoch, viz., the stratified Drift or Orange Sand, disappears beneath the water's edge near Port Hudson; while the swamp, lagoon and fluviatile beds, which have given notoriety to the latter locality, are seen above high water level not much farther south than the city of Baton Rouge.

The gradual descent and successive disappearance of these strata is not, however, altogether a phenomenon of dip, in the

* This Journal, II, vol. xlvii, Jan., 1869; Ibid, xlviii, Nov., 1869.

† For material assistance in the investigations embraced in this paper, I am especially indebted to the officers of the Delta Survey in charge of the Coast Survey schooner Varina—Messrs F. P. Webber and Henry L. Marinden, for reports of observations, and specimens furnished; to Capt. Day, in command of the same vessel, then moored at the Head of the Passes, for a boat's crew and personal assistance in the examination of the mudlumps; to Mr. Moulton, of the Cromwell line of steamers; to Captain Ed. Yorke, of the Towboat Association, and to Capt. Andrews, then of the dredgeboat at the Southwest pass, for free transportation on their respective vessels; and to Capt. Tilford and other gentlemen of the N. O. Pilot Association, for generous hospitality as well as much valuable information. For similar favors I am indebted to Dr. Copes, President of the N. O. Acad. of Sciences, as well as other members of that body. Other acknowledgments will be found in their proper place.

usual sense, but in a great measure the result of consecutive deposition; while the *surface* slope of the Port Hudson deposits is manifestly in a great degree due to denudation, and in part, no doubt, to deposition on a sloping bottom. At Port Hudson as well as elsewhere, where extensive profiles can be seen, the deposits of that era exhibit the basin shape; both on the large and, sometimes, on the small scale. In this as well as in their lithological and paleontological features, they greatly resemble deposits now forming over large areas; and where the two are in juxtaposition, it is often difficult, sometimes impossible, to draw the line between them, since qualitatively their process of formation has been manifestly the same. Both above and below Port Hudson, and down as far as Fort St. Philip, the *apparently alluvial* river banks frequently exhibit at low water edge, solid blue clays, with cypress stumps and twigs imbedded therein, scarcely distinguishable from some materials occurring at Port Hudson, Côte Blanche, and other localities *of the Port Hudson age*; and as neither can be expected to contain any but living organisms, it is, thus far, from general considerations alone, that we can hope to deduce their real age. It might seem, at first sight, that the distinction is practically of little moment; but when it is considered that the Port Hudson deposits are separated in time from those of the present era, by a large portion of the "Champlain" period of depression, *plus* the entire "Terrace" period of elevation, it becomes obvious that the distinction is one of no little theoretical, and some practical, interest. For while the Port Hudson strata yield to the augur almost invariably a considerable rise of artesian water, no such result can usually be looked for in either river or delta deposits.

I think that a retrospective view of the geological history of the lower Mississippi Valley and Gulf Coast, as developed by my observations in the States of Mississippi and Louisiana, will serve to show the probability that by far the greater portion of what now constitutes the alluvial plain of the lower Mississippi, is covered by the river deposits to a comparatively insignificant depth only; excepting where the ever shifting river channel itself has caused an unusual depth by excavation and subsequent filling up.

I have shown that toward the close of the Drift period, the place of the present Mississippi was occupied by what, but for its stupendous proportions, might be termed a torrent of fresh water, having, even as far south as the present coast line, a velocity sufficient to transport pebbles of five to six ounces weight, from localities not nearer than Tennessee and northern Arkansas; together with the smaller ones derived, doubtless,

from the same sources as the drift boulders of Missouri and Illinois.*

In the bored wells of Calcasieu, these pebbles have been found as much as 450 feet below tide level; the inevitable inference being (provided the sea level remained constant), that since the time of their transportation, the coast has suffered a depression to at least *that* extent—in matter of fact, probably, fully twice that amount.† The thickness of the drift stratum is about one hundred feet, the materials growing finer toward the top; indicating, therefore, a diminished velocity of the depositing current.

Overlying this sand and pebble drift, we find, as at Port Hudson, alternating strata of more or less lignitiferous clay and sand, 350 feet thick; a 130-foot clay bed lying on top. In its uppermost portion, this bed recalls to mind at once the variously colored clays of the Côte Blanche profile, with their calcareous concretions; but here, according to the concurrent testimony of the inhabitants and the microscope, *marine* shells take the place of the fresh-water fauna observed at the former locality. The sands which, on the whole, predominate in the lower portion, are readily distinguished under the microscope from those of the drift, by the predominant sharpness of the grains, and the occurrence of particles of lignitized wood; but I have not thus far succeeded in finding in them any other organisms. They resemble strikingly the materials obtained at corresponding depths in the bored wells in the city of New Orleans.

Few deep wells exist near the coast, in the interval between that city and the Calcasieu bores. In the only one of which I possess definite data, viz., at Salt Point on Bayou Salé, a bed of marine shells was found after passing through the first clay bed, at 60 feet.

* Miss. Rep., 1860, p. 26 and ff.; this Journal, II, May, 1866; and Nov., 1866; Ibid. Jan., 1869; Ibid, Nov., 1869.

The magnitude of this phenomenon would give it a continental significance even if it were confined to what I have termed the "Orange Sand delta," below Cairo. But as I have elsewhere stated, similar pebble streams, with slack water deposits of ferruginous sands intervening, exist in Texas; and I have the satisfaction of adding to the array of facts heretofore presented in connection with this subject, the testimony of Prof. Safford, of Tennessee; who, upon discussion, finds that the phenomena presented by the "Bluff gravel," "Ore region gravel," and "Eastern gravel" of his report are most satisfactorily accounted for, and brought under a common point of view, upon the basis set forth in my publications, above referred to.

In connection with Tuomey's and my own observations in Alabama, and farther east, those of Prof. Safford acquire additional significance, and the southern stratified drift an additional claim upon the serious attention of American geologists. Compare Prof. Newberry's interesting paper on "The Surface Geology of the basin of the Great Lakes, and the Valley of the Mississippi," where it is stated that "no deposits corresponding to the drift of the northern and western states, exist south of the Ohio river," (Ann. Lyc. Nat. Hist., N. York, ix, 213, 1869).

† This Journal, II, Nov., 1869, p. 335.

The same is true of the formation skirting the coast of Mississippi Sound. Deep wells there sometimes, though not always, strike beds of marine shells, and water possessing a considerable rise, after penetrating the uppermost clay bed; which *there* usually also contains cypress stumps, and forms the "blue clay bottom" of the Gulf coast. Sometimes, though rarely, deposits of marine shells, of living species, appear in the beds of streams. But so far as I know, their occurrence is limited to within a moderate distance from the general coast line; so that the great body of the formation underlying the upland parishes of East Louisiana, the Attákapas and Calcasieu prairies, as well as the coast-belt of prairies in Texas, consists of marsh, lagoon, and fluviatile deposits, with, probably, many an inlet or estuary of a more or less brackish or marine character.

Obvious as is the conformation of this littoral belt to the outline of the Gulf coast, the Mississippi valley influences it only in so far, as that its strata have here, probably, their highest absolute elevation,* and farthest extension northward. The latter circumstance is the natural consequence of the existence of the depression which, at least since the opening of the Cretaceous period, has determined the outline of the formations southward of Cairo—an embayment which, with every succeeding period of deposition, became less concave, until at the close of the Grand Gulf epoch, the concavity had all but disappeared. During the period of slow depression which characterized the Port Hudson era, the present general coast line must have been established; and when upon the reversal of the movement of subsidence, the waters of the continent began to be discharged through what is now the lower Mississippi valley, the erosion seems to have been checked everywhere, save perhaps in the main channel, by the tough cypress swamp clay which now forms the immediate substratum of the lower littoral belt, and extends far into the waters of the Gulf.

It is incredible that the deposition which occurred along the whole Gulf coast from Indianola to Mobile, should not have taken place also in the main axis of the depression which, as the trend of the formations shows, had in a great measure been filled up. Yet, inasmuch as this was the deepest portion of the area, it is to be expected that here, if anywhere, marine deposits should extend far inland. We shall not therefore be surprised to find that, as Pourtalés has proven from the soundings made under the direction of Gen. Humphreys, the Mississippi river flows on marine beds, at New Orleans and Bonnet Carré. It would rather be remarkable if such beds should *not* appear even much higher up the river, since even in the comparatively

* As regards the main body. At Weeks' Island and Petite Anse, and probably at Côte Blanche and Orange Island, their elevation exceeds that at Port Hudson bluff.

insignificant valley of Pearl river, they have been met with in the latitude of Baton Rouge,* about 30 miles from the coast.

It is, doubtless, owing to the formation of these swamp deposits, and their subsequent resistance to denudation during and since the Terrace epoch of elevation, that the main body of the truly alluvial delta is thrown so far beyond the general coast line,† out into the Gulf. It is the shallow "blue clay bottom," so well known to navigators on the Gulf coast, which forces the great river to advance its mouths so rapidly toward deep water, by the accumulation of its own deposits; and the borings made at New Orleans have shown how slight is the thickness, even at such an advanced point, of the river deposits proper, overlying the older formation.

I owe to the active interest taken in this subject by Gen. A. A. Humphreys, U. S. A., an opportunity of examining, not only the specimens collected during the boring of the artesian well at New Orleans by a committee of the New Orleans Academy of Sciences (so far as they were preserved from destruction during the war); but also those obtained in the soundings made by the delta survey under his charge, upon which a very able and minute report of a microscopic examination had previously been made by Mr. L. F. Pourtalés. Upon the strength of the data furnished by the latter, as well as by the profile constructed by the committee of the Academy (reproduced in the "Report on the Physics and Hydraulics of the Mississippi river"), Gen. Humphreys concluded that at Bonnet Carré and New Orleans, the river flows on an ancient sea bottom, which he conjectured to be of Tertiary age. Sir Charles Lyell having questioned the correctness of this view, Gen. Humphreys obtained from the N. O. Academy as complete a suite of specimens of the borings as could be collected, and referred them to me for examination. The first results of this investigation are given, in substance, in the first volume of Lyell's Principles of Geology, 10th edition, p. 459; they were based substantially upon the determination of the visible shells (mollusks) contained in several of the specimens, embracing, fortunately, most of the important horizons mentioned in the profile. I have since gone over the whole ground, in the microscopic examination of all the available specimens, with a view to determining their (marine or fresh water) character, and the admissibility of the supposition that they might belong to the delta formation proper.

My detailed report of this examination will, I presume, be published before long.‡ Unfortunately, most of the specimens

* Miss. Rep., 1860, p. 156.

† Drawn, say from the mouth of Pearl river to Belle Isle, the most advanced outpost of the Port Hudson deposits on the Louisiana coast; which line will pass near the city of New Orleans.

‡ In Rep. of the U. S. Engineer Dept., for 1870.

representing the important clay strata (of 34, 32½, 39, and 63½, feet respectively), were missing; but as regards the rest, 51 in number, I found almost all derived from a lower level than 31 *feet*, either characterized by marine organisms (shells, corals or foraminifera), or of such a character as, by their obvious connection with the others, to put them in the same category, although devoid of fossils. I cannot omit to mention in this connection, the extraordinary scarcity of marine organisms in some of the specimens brought up in sounding *off*, *on* and *inside* the bars of the Mississippi Passes; the most patient search, even after concentration by washing, having failed to bring to light anything but minute fragments of wood, root and other vegetable fibers, and remnants of Naviculæ. These specimens had, it is true, been obtained during a period of high water; and others, collected at corresponding points but at a different season, showed abundance of foraminifera and even some visible shells. But in view of these facts, it is quite intelligible how in an estuarian formation, forming at the outlet of the continental waters, many portions may have remained destitute of any vestige of marine life, though perhaps deposited in strongly brackish water; while any slackening in the rate of depression would promptly cause a predominance of the fresh over the salt water, a stagnation, and consequent deposition of clays; which would be nearly or quite free from vestiges of marine life. Such is the case in *some* of the few clay specimens from this bore, which I have had the opportunity of examining; but others I have found to contain not only foraminifera, but abundance of shells. In the clay occurring at the greatest depth reached—630 feet—Mr. Pourtalés reports an abundance of foraminifera.

The specimens from the several beds contained altogether about 50 species of mollusks, of which 40 were in such a condition as to be determinable with certainty. Of these, 36 were species now living in the Gulf, and 4 were new.

The latter (belonging to the genera *Cardium*, *Abra*, *Semele* and *Tapes*) I submitted to Mr. Conrad for determination and description. He remarks that while they (one of them especially) seem to be rather of miocene type, and not known to be now living in the Gulf of Mexico: yet our knowledge of the fauna of the latter is so imperfect thus far, that it cannot be asserted that the species are not now inhabitants of the Gulf waters.

As regards the distribution of the species, there is no material difference from the highest to the lowest level, the leading and predominant species being everywhere about the same, and coinciding in a marked manner with the fauna collected by myself on the beach of Ship Island in the Mississippi Sound;

though quite different in the prevalence of species, from that now cast ashore on the islands of the delta. One of the new species, moreover, occurs abundantly in one of the very first shell-beds; and three of them at the depth of 235 feet, as well as, in part, still lower down.

In view of all the facts bearing on the case, the most probable conclusion is that the marine formation penetrated in the New Orleans well is altogether independent of the present delta formation; that, on the contrary, it is the equivalent in time of the Port Hudson deposits, which everywhere near the coast assume a marine facies; and would necessarily possess that character in an increased degree, where the deepest depression existed.

The thickness of the alluvium proper in the alluvial plain will, of course, vary in accordance with the degree of denudation that the older formation may have experienced during the era of upheaval; and it is futile to attempt an estimate of the amount of alluvium deposited by the great river since the beginning of the modern era, until numerous observations shall have placed us in possession of data allowing us to form an approximate estimate of its depth in the several portions of the alluvial plain. While there exist in it, doubtless, a number of ancient river channels, we already have proof also of the existence of ridges of more solid and ancient ground, far out in the delta plain, which seem to have caused the eastward deflection (parallel to the Tèche and the main Mississippi), of Bayou Lafourche as well as of the minor channels. I have heretofore* alluded to the apparent *general* cause of this deflection, viz., the barrier of drift materials accumulated, perhaps, upon a Cretaceous nucleus, which is presented by the chain of Five Islands—Belle Isle, Côte Blanche, Weeks' Island, Petite Anse and Orange Island—extending from Atchafalaya to Vermilion Bay.

The very variable depth of the alluvium is well exemplified by the borings made for water and gas, in the city of New Orleans, by Mr. J. B. Knight, of that city. Its lower limit seems to be almost everywhere marked by a stratum of liquid mud, beneath which appears the first shell bed. It is from this mud stratum, which is struck at depths varying from 31 (in the well of 1856) to 56 feet, that combustible gas is frequently found to issue in considerable abundance, and with a pressure (as reported by Mr. Knight) of from $1\frac{1}{2}$ to 3 pounds per square inch. The discovery (which was made by Mr. Knight in boring an experimental well for water, on his premises) at first created considerable excitement, as it was thought the natural gas might successfully compete with that of the gas company,

* This Journal, II, Jan., 1869, p. 88; ibid, Nov., 1869, p. 343.

which it was said to equal in quality. That this was but an indifferent compliment to the company's product, may be judged from the composition of the natural gas, which was analyzed by Prof. J. W. Mallet, then of the University of Louisiana, with the following result:

Gas from "Knights' well," 170 Gravier street, New Orleans.

Marsh gas,	91·81
Carbonic acid,	2·97
Nitrogen,	5·32
Hydrocarbons condensible by bromine,	trace
	100·00

The gas issued at the rate of one and a half cubic feet per hour, with a pressure of 1·6 inches of mercury. It was reached at a depth of 40 feet, and was accompanied by a considerable flow of faintly saline water.*

Mr. Knight sunk numerous wells in different portions of the city, and states that gas was struck nearly everywhere at depths varying from 37 to 56 feet; its amount, in one and the same region, being sensibly proportional to the diameter of the bore. In a few cases, an extraordinary amount of gas, under strong pressure, was struck. In an article published in the New Orleans Times, of March 19, 1870, it is stated that "at the old Washington Artillery building on Girod street, a pipe was driven for water, and the gas flowed through in such a volume, that when ignited it fed a flame 15 feet in height, which was with difficulty extinguished; and when it was at length choked out, it carried up several cart loads of sand in a single night. Yesterday a similar phenomenon presented itself on the edge of the sidewalk in Camp street, opposite Lafayette square. A pipe about an inch and a half in diameter had been driven into the ground for water, when at the depth of 60 feet, a rush of gas, accompanied by water and sand, was forced through to a distance (height) of twelve or fifteen feet above the top of the pipe. This continued for two hours, in spite of all efforts to suppress it; and the result was a deposit of sand mixed with fine shells and pebbles, amounting to at least three cart loads. Finally the workmen succeeded in closing the pipe, and forcing it through the gas-bearing stratum."

The supply of gas was in the end, however, thought inadequate for practical purposes; while the original object of obtaining drinkable water was attained to a limited extent only. Mr. Knight says in a letter on the subject, that he has "found great irregularity in the thickness and character of the strata,

* See analysis beyond.

and it is impossible to tell the character of the water or the depth at which it will be found, before trying. At two places distant about 1,500 feet, I obtained, in one, at the depth of 48 feet, a free supply of clear water strongly impregnated with iron; in the other, no such water could be found at the depth of 78 feet."

Attention having been called to the subject, a "find" of gas was next reported from the parish of Lafourche, said to rise with a pressure of 10 pounds to the inch. I have been unable to learn whether or not this occurrence of gas is identical with that described to me by Col. Thibodeaux, of Thibodeauxville, as keeping up a continual agitation of the waters of the "Bayou bouillant," on the lower Lafourche. So far, no practical application of this source of gas has come to my knowledge.

As regards, then, the upper delta plain, there can be little doubt that, like the Calcasieu and Attákapas prairies, it is underlaid by the detrital deposits of the stratified Drift, at a depth which may fairly, *à priori*, be supposed commensurate, in a measure, with the importance of the neighboring channels; viz., the Sabine on one hand, and the Mississippi on the other. About midway between, the Cretaceous ridge marked by the line of outliers from Lake Bisteneau to Chicotville or Petite Anse, has caused these same deposits to appear at the surface.* The overlying swamp, lagoon and estuarian deposits of the Port Hudson age, will vary both in thickness and in the (marine or fresh-water) character of their materials, in accordance with the conformation (relative to the ocean) of the surface upon which they were deposited. And the alluvial deposits proper will, in like manner, vary in thickness in accordance with the degree of denudation previously experienced by that older formation, but appear to be little greater on the alluvial plain near New Orleans, than it is sometimes found to be in the Yazoo and Tensas bottoms.†

It is important to note that, under this point of view, the ultimate success of an artesian bore at New Orleans becomes a matter of certainty—a question of depth alone. All water obtained in the Port Hudson strata possesses considerable rise, but is usually too strongly mineral to be desirable for everyday use. The waters obtained in the Orange Sand, on the contrary, are always remarkably pure, and when struck *beneath* the Port Hudson deposits cannot fail to possess a proportionate rise, as in Dr. Kirkiman's bore, on the West Fork of Calcasieu. The waters of the Port Hudson strata would, of course, require to be tubed out.

[To be continued.]

* This Journal, II, Nov., 1869, pp. 332, 342 and ff.
† Humphrey's and Abbot's report, pp. 98–100, et al.

II. *The Lower Delta and the Mudlumps.*

A glance at the map shows that in descending the Mississippi from New Orleans, we find a narrow strip of land only ¾ to 3 miles wide, dividing the river from the waters of the Gulf; from the head of Oyster Bay opposite Pointe à la Hache (about half way between the city and the head of the Passes), down to the mouths. Such, at least, is the case on the left bank; on the right, the "neck" begins a few miles below Fort Jackson. Down to the forts, the aspect of the "Coast" is generally pretty much the same, where its original character has not been lost by cultivation or encroachment of the river. Nearest the river, and highest above water level, are the sandy "willow battures," where the willow, mingled with and occasionally replaced by the cottonwood, forms the predominant growth. Beyond lies a belt of woodland, timbered chiefly with live-oak, magnolia, and cottonwood, often deeply veiled with long-moss; this belt embraces the richest and most durable soils of the "Lower Coast," and is mostly occupied by magnificent plantations of sugar cane and orange orchards. Beyond these, loom in the distance the sombre-hued, moss-curtained denizens of the cypress swamp, their tops forming a level platform sharply defined against the horizon. Between the swamp and the water's edge, seaward, there usually intervenes a zone of reeds, with here and there a stunted cypress, bay, or candleberry bush, where the salt water has but slight access.

While such is the general order of succession of these belts of vegetation where they coëxist, either or both of the two middle ones may locally be absent. Such is always the case where the "neck" is very narrow, as happens below the forts. Thence to the mouths of the passes, the willow batture and the reed marsh alone, with few exceptions, form the barrier between the river and the sea; it is traversed by numerous small bayous, some of which are in great part the work of the duck-hunters that supply the New Orleans market, and whose pursuit leads them to penetrate the marsh for the purpose of reaching the favorite resorts of their game. These bayous increase in frequency as we descend, and in approaching the mouths of the passes, the intervals between them become smaller, until they gradually become sheets of water dividing islands; and finally, just inside the bar, we have the latter resolved into numerous individual "mudlumps," dotting the surface of the sea, on both sides of the main channel.

Sir Charles Lyell remarks (Principles of Geology, 10th ed., p. 448), that the phenomenon of the mudlumps is without parallel, so far as known, in the delta of any other river. The same remark might, I think, appply to two other peculiarities, viz: the protrusion of the long neck of land into the Gulf; and the fact that, after failing to send out any branch of importance for a hundred miles the great river suddenly divides at one point into three widely divergent branches, the middle one of which (the South Pass), forming the direct continuation of the channel, is the smallest, and has long ceased to be navigable. Evidently, a strong extraneous obstacle alone could turn aside the powerful current, and permanently resist its erosive and undermining action. And now, the channel which carries the main current (the Southwest Pass), faithful to the old tradition, is rapidly pushing out into the Gulf its narrow bands of reedy marsh, without a branch of any consequence in ten miles from the head of the Passes to the light-house.

A glance at the coast lines, as well as at the intricate ramifications characterizing the deltas of the Rhine, the Po, the Danube, the Ganges, or the Hoang-Ho; or the broad inlets forming the mouths of the rivers of South America, will show the uniqueness of the Mississippi mouths; the Nile and the Lena alone exhibiting a general form at all analogous, yet very distinct in detail. For the islands off the Lena mouths are not "mudlumps;" and the tongue of land separating Lake Menzaleh from the Damietta branch of the Nile, is a mere sand-bar. exhibiting no analogy save that of form, with the remarkable "necks" of the Mississippi Passes.

It would be fair to infer, à priori, that some connection exists between the exceptional phenomenon of the mudlumps, and the exceptional form of the delta: and that such is really the case, can hardly be doubted upon a candid investigation of the facts. So far from being an unusual phenomenon, *the mudlump-formation appears to constitute the normal mode of progression of the Mississippi mouths;* not only at the present time, but for many ages past; perhaps ever since the broad flood of the Terrace epoch subsided into the present Mississippi.

The characteristic features of the mudlumps have successively been described and discussed by Sidell,* Forshey,† Chase, Beauregard and Latimer,‡ Thomassy§ and Lyell.‖ Yet as the phenomena are nowhere described in their entirety, I will here, as briefly as possible, recapitulate the important points.

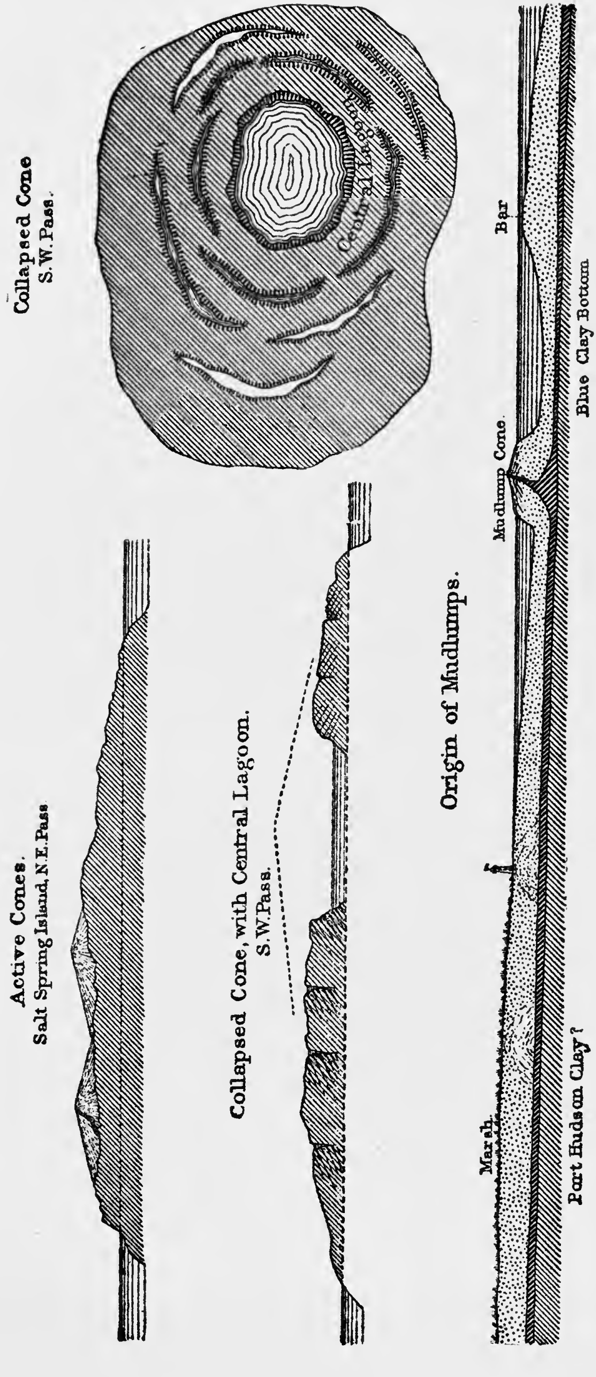
* Report to Capt. Talcott, 1839, in Humphreys and Abbott's Report, App. A.

† MS. Report, 1850.

‡ Report of the Board of Engineers for the Examination of the Mississippi; Congress. Doc. 1852–53.

§ Geologie Pratique de la Louisiane, 1860, Chap. VI.

‖ Principles of Geology, 10th edition, 1868; vol. I. p. 449.



MUDLUMPS OF THE MISSISSIPPI DELTA.

The mudlumps originate in upheavals of the bottom, in the region lying between the extreme point of the mainland and the crest of the bar, at the main outlets of the passes. They all lie within a distance of from one to three miles from the axis of the main current, and nowhere extend into the bays intervening between the several active mouths. The pilots are under the impression that they form more frequently in the main channel than elsewhere; but allowance must be made for the natural infrequency of their observations outside of the latter; so that only the more obvious and remarkable changes of the bottom, when occurring outside of their regular range, would be likely to come under their notice. *A priori*, it would seem probable that inasmuch as the resistance to the upheaving force, other things being equal, must be less in deep than in shallow water, the lumps would rise more frequently and more rapidly in the channel than elsewhere. On the other hand, the denuding force of the river current must greatly diminish the chances of any such upheaved mass appearing above the surface, or even becoming manifest by a diminution of depth, when progressing slowly. Weighing these considerations against each other, I think a balance remains in favor of the pilot's opinion; the more as concurrent testimony goes to show that whenever the channel is changed, either by the accumulation of deposit or the interference of a mudlump upheaval, the old channel is promptly occupied by mudlumps *throughout* the abandoned portion.

As regards the rapidity of the upheaval, it appears to vary from an almost secular rate, to that of several feet in 24 hours. It has been rumored that lumps had been seen to rise visibly, and burst open like a bubble, but I have been unable to trace the statement to any reliable source, and it is discredited by the pilots. The most rapid rise of which I have obtained reliable information was witnessed by Capt. Andrews, of New Orleans. He states that a steamer having run aground about nightfall inside the bar, her bow being on a mudlump in about $2\frac{1}{2}$ feet of water, he towed her off during the night, and in the morning found the imprint of her bow 18 to 24 inches above water, in the soft mud. Allowing for the possible maximum influence of tides in favor of the difference observed, the minimum rate of upheaval, according to these data, still amounts to one inch per hour. Nor is this the only case in which a rapid shallowing of the water has been observed as a consequence of the grounding of large vessels. This has usually been ascribed to the accumulation of deposit in the slack water so formed, and in many instances this may have been the true cause. But this explanation can hardly apply to the case detailed above, and it is reasonable to suppose that the shock of a grounding vessel may

in many cases prove "the hair that breaks the camel's back," when acting upon a portion of bottom just about to yield to the upheaving force, and therefore in a state of unstable equilibrium. Future observations, however, will readily settle the question.

Of authentic observations illustrating ordinary rates of rising, I quote the following remarks of Mr. H. L. Marindin, U. S. Coast Survey, who in 1867, while engaged in the survey of the mouths, at my request paid considerable attention to the phenomena of the mudlumps, and made an interesting report to me on the subject, dated June 20th, and accompanied by specimens.

"Since the first examination of the mudlumps on Southwest Pass Bar, there have appeared numerous lumps in the vicinity of the main channel, whose appearance cannot be attributed to other causes than the upheaval of the bottom by some unknown agency; since tidal observations made during the month of April, May and part of June, show no material decrease in the height of water in the river, other than the daily ebb of the tide. In one instance, also, on this bar, it has been ascertained from surveys made at different times, that where in the month of April a channel with fifteen feet of water existed, there is now a lump, doubtless still forming, with only six feet of water on it at the highest stage."

Making allowance for a possible accumulation of deposit, the rate of rise cannot, in this instance, be estimated at less than two feet per month; which, so long as the lump remains under water, seems to be no unusual amount. When, however, the surface of the water is once reached, the rising becomes slower or ceases altogether, owing probably to the greater weight acquired by the material upon its emergence. At least, I have failed to find much above tide level, any material which did not bear distinct evidence of its having been formed, not by river alluvion, but by the action of the regular mudsprings; which, if not now active upon all the lumps, have demonstrably been instrumental in forming the great majority of the masses now above water level.

I do not know that any one has ever witnessed the first outburst of a mudspring on a newly risen lump; but we find them in all stages of progress, from the islet bearing its first tuft of rushes, to the active cones glistening in the sunshine, and from time to time, when an unusually large gas bubble rises, spattering the liquid mud (which usually flows in a quiet stream) all over the slopes; then the half-extinct cone, in whose crater a little pool of salt water is at long intervals agitated by a gas bubble; then the extinct and collapsed cone, surrounded by a circular moat and Somma-like ring-wall; next, the old lump of

jagged outlines, whose disintegrated materials are rapidly yielding to the combined attack of rain, sunshine and waves, till something looking like a large stump of a tree is all that remains of an island of several acres; and finally the shoal, marked by dangerous rollers, whose surface, on a calm day, still exhibits the concentric markings corresponding to the several cones which originally built up the island.

I regret being unable at the present time, to present accurate sketches of these several stages of " the mudlumps' progress." I hope to do so hereafter, but for the present must confine myself to the approximate outline representations given in the plate, and a brief description of the several stages as observed by myself in 1857.

Nascent Lumps.—As regards the first, it is probable that a good many lumps never pass beyond that stage of development, for the reason that, so soon as the resistance is materially increased by the emergence of a portion above the surface of the water, the upheaving force seeks a vent elsewhere.

Either the mud or gas-spring breaks out beneath the water, and becomes perceptible only by the more or less regular and localized evolution of bubbles on the outskirts of the lumps; a very common phenomenon in the neighborhood, not only of new and active lumps, but also about extinct ones, which are in course of demolition by the waves. On the extensive sandy shoal off Stake Island, on the Southwest Pass, such subaqueous gas-springs may be observed in great numbers.—Or it may happen, that another portion of the bottom, now offering less resistance than the mudlump, will, in its turn, give way before the upheaving force, till the same degree of emersion is obtained, or a vent is opened.

I have been unable to ascertain how high any mudlumps can rise bodily above the water without the appearance of a vent. As much as three feet has been observed with certainty; but unless the fact that it is a new upheaval be historically known, it must be extremely difficult to ascertain it, unless, by actual access to the interior, it can be shown that its surface strata are old river deposits, which can readily be distinguished from those formed by mudlump vents. Yet these might, during the elevation of the lump, have been removed by the current. At all events, I have failed to find on the surface of any lump much above tide-water, anything like true river alluvium; the visible material being either such as is now formed by active vents, or, (as on the lower slopes), that which obviously results from the disintegration of the former, being altogether devoid of structure.

It is said that lumps sometimes sink from view again after bare emergence. I know of no authentic example, but it

seems likely enough that upon the formation of a large vent elsewhere, such a thing might happen; especially if, as I think probable, mudsprings and mud-cones form *beneath*, as well as above the water.

Active Cones.—In the second stage, that characterized by the formation of the active eruptive cones, mudlumps offer an aspect so strikingly like that of the mud volcanoes of Tuscany, as to stagger the observer's geographical consciousness. The most striking example of the kind existed, at the time of my visit, off Pass à l'Outre, on the south (right) side of the channel. The island* is about an acre in extent, and besides the active vents (of which there are seven), we perceive on the southern portion the remnants of long extinct craters, in various degrees of advancement toward old age and degradation, and partially covered with vegetation.

The cones on the north or channel side, at a distance, present a glistening surface, and those possessing a central vent only are very regularly and smoothly conical. Of these there are four, the diameters of the bases ranging from eighteen to fifty feet, and their elevation from one to two and a half feet above the general level of the island; making the angle of the slope from 5° to 8° only, instead of 25° to 35°, as given in the published sketches. I have seen no undisturbed cone whose slope exceeded about 12°. The slope is, of course, essentially a function of the thickness and character of the mud; which in the present instance flows from the circular basin at the summit, 4 to 8 ins. in diameter, in a regular, creamy stream, interrupted occasionally only by a gas bubble; which, if the mud be thick, spatters it about to some extent. The mud-stream varies from 3 to 4 gallons per minute in the largest (eastern) cone, to a pint or two in the less active ones; sometimes, in running down the sides, it spreads over as much as $\frac{1}{3}$ of the circumference, but usually forms a stream 4 to 8 inches wide, serpenting down the slope between banks formed by its own solidification, as does a lava stream. As these banks grow in height by drying, on the edge of the crater, they gradually compel the mud to rise higher before it can flow off; whereupon, after a while the column overflows at another point of the circumference, where the same play is then repeated. In the meantime, the previous mudstream has an opportunity of consolidating, drying more or less, and undergoing a variety of chemical changes dependent upon the character of the water and the duration of the exposure to the air, which manifest themselves in changes of color and consistency; by these the individual streams are distinctly defined from one another. Each one forms, of course,

* It was named Marindin's Lump by the crew of the U. S. Coast Survey Schr. Varina, and I shall allude to it under that designation.

a more or less irregular portion of a conic surface, the cross section being more or less lenticular.

There results, as may be supposed, a very peculiar structure or stratification, unlike anything usually seen outside of volcanic districts, unless, perhaps in the somewhat analogous case of the lee side of dunes. It may roughly be compared to the upper half of an onion. It is needless to say that, once seen, it cannot readily be mistaken for anything else; and its absence must be held as proof conclusive of an absence of genetic analogy.* The thickness of the layers rarely exceeds $1\frac{1}{2}$ inches; their colors vary from dark mouse-color and bluish gray, through dun and buff, to rust-color and red; the materials, from hard, plastic clay, always containing a great deal of fine silex and more or less coarse sand, to sandy clay and, rarely, clayey sand; the selvedges are frequently marked by iron rust and mica scales. Where, as is frequently the case, neighboring cones are confluent at their bases, the structure is of course complicated in a manner readily imagined.

As regards the gas evolved (which is in all cases inflammable), the small proportion its bulk bears to that of the mud simultaneously ejected (about $\frac{1}{25}$ to $\frac{1}{30}$ at Marindin's Lump), at once does away with the impression mostly entertained, that the gas bubbles bring up the mud with them. The latter comes up with a steady flow, evidently the result of static pressure, and is only from time to time agitated by a gas bubble, larger or smaller according as the mud is more or less consistent. We sometimes find, about extinct cones especially, lively gas springs in which the proportion of gas is considerably greater, than happens in any active cone that has come under my observation; but in that case, it is almost always accompanied only by *water*, as though its source were above the stratum which furnishes the mud. For, a glance at the river deposits forming around the lumps, at once shows that they are totally different from the fine, clayey material of which the cones are formed; nor is it credible that the mere passage of a current of water and gas through such deposits, or in fact, *any consolidated materials*, should produce such a perfect, creamy mixture as that ejected from these craters.

Extinct Cones.—Good examples of cones whose activity has nearly or quite ceased, may be seen off the Northeast Pass. Here the material is somewhat sandier and firmer than the mud ejected at Passe à l'Outre. While at the latter place it was difficult to reach the craters without being hopelessly

* Vide Thomassy's remarks on the Five Islands, etc., Géol. prat. de la Louisiane, chap. viii. With even less show of reason a similar origin has repeatedly been claimed for the low circular mounds which dot a large part of western Louisiana. They consist exclusively of unstratified sandy materials, and are doubtless the result of animal activity—probably of the large ant.

bogged, they can readily be reached almost dry shod at the Northeast Pass. Here, also, the top layers were peeling off in large concave "flakes," from the effect of sun-cracks and drying; such a surface again overflowed by mud would add another singular feature to the structure of the cones, which may also be noticed in many sections of ancient ones.

The vent of a large cone in this region (see Plate) formed a basin about 8 inches diameter, containing a puddle of salt water covered with an iridescent ferruginous pellicle, disturbed at long intervals by small gas bubbles. Evidently, the resistance in the large cone, elevated about 10 feet above the water level, had become too great for the ejection of mud; in consequence whereof, a lively little cone was glistening and bubbling at a level several feet lower, near the foot of the old cone. *But the testimony of the pilots goes distinctly to show, that the active cones become more lively, and dormant cones resume their activity, at high stages of water in the river.* At the time of my visit, the water was at an unusually low stage.

Collapsed Cones.—The cones, especially the larger ones, appear to be unable to survive for any great length of time the cessation of activity. The change that occurs seems to be, in all cases, a sinking of the central portion, often to such an extent that its place becomes occupied by a pool or lagoon, surrounded by a circular rim whose strata incline *away* from the center at angles invariably much steeper than is found in any recent cones, from 20° to as much as 45°. Outside of this first rim there mostly appears a series of concentric crevasses, sometimes several feet in width and in depth; and the annular segments thus brought to a level by a subsidence, also exhibit the singular feature of a *steeper* inclination of the lines of deposition, than is found in any cones now forming. The seeming anomaly of this fact caused me to observe the phenomena closely; but I have been unable to find an exception to the rule; and I have been led to doubt whether in some cases, instead of true eruption cones, these collapsed areas and their surroundings may not be the remnants of the original upheaved "bubble." The objection to this interpretation is the character of the material, which, excepting in a few cases on the Southwest Pass, is altogether unlike the present river deposits, both in structure and composition.

A most perfect exemplification of a large central lagoon (100 feet by 75) surrounded by an elevated rim and several successive, concentric "moats," also in part filled with water, occurs on one of the numerous mudlumps S.W. of Stake Island, on the Southwest Pass (see Plate). The central portion does not always, however, sink out of sight; sometimes a conical mound is still observable, as the center of the more or less circular,

concentric crevasses, which a close inspection shows to exist on almost all lumps not too far advanced towards decrepitude. Many islands exhibit several such centers and systems of crevasses, indicating, probably, the previous existence of cones, sometimes several hundred feet in diameter, greatly exceeding the largest now in a state of activity, both in diameter and original height.

Degradation and Disappearance of Lumps.—The direct action of the waves, unassisted by atmospheric agencies, produces but little effect upon the yielding, but tough and coherent material of the cones. The heaviest breakers and rollers spend their force in vain against the clay shoals which render most of the lumps so difficult of access. The unwary will often be tempted by the deceptive, rock-like aspect of this material, to jump into the shallow water and wade ashore; but a plunge knee-deep into the apparent solid will frequently reward his temerity. Yet so long as this mass, which shows plainly the peculiar, concentrically banded mudlump structure, remains constantly covered with water, the waves rolling over it produce but little impression.

Not so with the portion that projects above water, which is alternately exposed to rain, sunshine, and the wash of waves. Especially where the material is clayey, these agencies combined soon produce a change in which the structural as well as the paleontological characters of the original material are totally obliterated. A rain falling upon a fresh surface of the latter, causes it to swell; then, upon exposure to sunshine, it will contract into prismatic cleavage-forms. A slight rain, or the spray itself, will then cause the extreme surface to crumble into, and partially fill up, the cracks; when the swelling consequent upon a thorough wetting, by either rain or waves, will force them to open still more, while streamlets of fluid mud follow each retiring wave; which, perhaps, has thrown up, and left high and dry in the cracks, a dozen species of shells, entirely foreign to the mudlump mud itself. It is thus that the structureless, tough soil of the general surface, and of the beach of the mudlumps, is formed; and to it alone apply the descriptions given of the mass of the mudlumps, by Sidell, Thomassy and Lyell, as a "homogeneous, tenacious mud."

A frequent repetition of this process involves, of course, not only a rapid direct degradation of the lump, but it causes it to be cleft into fragments by rents gradually progressing from above downward, which rapidly increase the surface exposed to attack; and eventually, some large wave, in retiring, carries down with it a huge prismatic slice, leaving behind an almost vertical cliff. This is carried away in its turn, and thus, attacked from all sides, an island of considerable size, after

passing through a variety of middle stages in which it strikingly resembles masses of trap or basalt, magnified into distant mountains by the peculiar optical delusion prevailing in the region,* is finally reduced to what, at a distance, appears to be the stump of a tree. At last, some storm sweeps away this last monument of the disappearing lump, and white-capped rollers alone mark, thereafter, the higher points of the mud-shoal.

I have best observed these phenomena of disintegration in every stage of progress, among the mudlumps off the Northeast Pass, where the fanciful, cliff-like forms, figured by Thomassy, Sidell, and Lyell, may be seen to perfection.

It is said that there are no mudlumps off South Pass or Grand Bayou; a statement which may require to be taken with a grain of allowance, but agrees with the general impression that the mouths discharging the largest amount of water, also exhibit mudlump activity on the most extensive scale.

The Southwest Pass is the main outlet at the present time; the area inside the bar is thickly studded with mudlumps, chiefly west of the channel; and as before stated, lumps have risen there repeatedly under the eyes of the pilots and survey parties. Yet there is not there, at the present time, a single *active* cone, so far as I am aware; although salt water and gas springs are of frequent occurrence, both on and around the islands. There is a marked difference between the river deposits as well as the mudlump materials of Passe à l'Outre and Southwest Pass, the latter being decidedly more sandy, and sand bars taking the place of the mud flats off the former. Whether this circumstance (the natural result of the greater swiftness of the current in Southwest Pass), is connected with the absence of active cones, it may be too early to discuss. Some very lively springs on a large mudlump off Stake Island on that Pass, in which the gas emitted is about equal in bulk to the water, rise in small basins excavated at the foot of a large cone which must have been 15 to 18 ft. high; but the material they bring up is so very sandy that the water runs off perfectly clear.†

Mudlumps in the Marshes.—I have before remarked, that at the present time, the upheaval of mudlumps on the passes, and subsequent silting up of the shallows between them (by river deposit, as well as by the degradation of the lumps themselves,) seems to be the normal mode of progression of the delta. The more advanced portions of the narrow bands of shore now

* Caused probably by a faint bluish haze, through which an island a quarter of a mile distant and 15 feet high, appears to be a wooded mountain with rocky escarpments, and at its foot a wide spreading city—which suddenly resolves itself into a row of grave white pelicans perched on the beach and taking wing at the approach of a boat.

† See analysis of the water of these springs, below; marked "S. W. Pass, I."

forming along each one of the passes, are historically known to consist of mudlump-chains; and in the absence of any plausible presumption to the contrary, as well as of any parallel example in other rivers, it is reasonable to surmise, that not only the shores of the present passes, but also the neck, *at least* from Pointe à la Hache down, owes it formation and peculiar features to the same agencies.

We have seen how rapidly and completely the joint action of the waves and atmospheric agencies accomplish the degradation of elevated lumps to the common level of the tide; and where the nature of the materials is such as to yield readily to these destructive influences, it would be unreasonable to look for vestiges of ancient lumps above that level. Such is the case, as before mentioned, on Northeast Pass and its branches.* But the sandier nature of the mudlump mass on Southwest Pass enables it to resist much longer, so that some of the larger and more elevated islands there seem destined to retain, more or less permanently, their present form. For the same reason, perhaps, the Southwest Pass furnishes the one prominent example of the existence of an active and characteristic mudlump, in the level marsh on the right of the channel, about five miles below the Head of the Passes, and seven above the mouth (light-house); distant $1\frac{1}{2}$ miles from the river bank, and about one mile from the beach of West Bay. Double-headed Bayou, or one of its channels, passes within a few hundred yards of this lump; which is so difficult of access that it has been very rarely visited, though plainly visible from the hurricane deck of passing steamers, from which I have examined it with the telescope.

According to Thomassy,† the pilot Ben. Morgan, who has visited it, describes it as being "a regular truncated cone, 20 to 25 feet high and 300 in circumference, spouting at intervals from its summit masses of clayey and sandy mud, which overflows all around."

From the Pass, it now appears as a slightly irregular, conical hill, which, judging from the extent to which it projects above the highest reeds, is about 18 to 20 feet high at most. On its eastern side there is a second cone about half as high, with a very regular slope not exceeding 30°, while that of the large one is at least 45°. A whitish sheen which extends from the summit of the larger cone toward the smaller one, I interpret as a white salty efflorescence; but on the south slope of the smaller

* Col. Sidell mentions a mudlump cone, 18 feet high, on the north side of the Northeast Pass, in the marsh. It has probably succumbed since his visit, as in passing the spot I was unable to perceive any elevation, nor was it known to the pilots.

† Géol. prat. de la Louisiane. p. 56. I shall designate this cone as "Morgan's Lump."

cone, the glittering of a flowing mudstream was unmistakable. Inasmuch as in Morgan's account of his visit the smaller cone is not mentioned, it is presumable that it has been formed since, by a lateral eruption; the old cone having, perhaps, reached the extreme limit of height to which mudlump force can raise its materials.

The steep slopes of both the old and new cone are suggestive as to the influence of sandiness on that feature, and the explanation of the steep inclination of strata, observed chiefly on Southwest Pass.

It is my impression that another cone exists in the marsh about two miles south of these. It is almost screened from view by the reeds, but the telescope shows it to be distinctly conical. It does not seem to have attracted notice heretofore.

But if mudlump cones are scarce in the marshes, the same is not true with reference to the salt and gas springs, which are reported to be quite abundant by the hunters—the only men whose occupation leads them to "thread the pathless waste" of reedy marsh, otherwise seldom visited, save by surveying parties, and alligators. These springs are found on or around all mudlumps, of whatever age; even on the shoals left behind by disintegrated lumps, where they issue under water, sometimes altering perceptibly the character of the water in the immediate neighborhood. The Southwest lighthouse was originally built on a mudlump separated from the mainland by a bayou; this is now filled up, but salt springs still issue at several points in the marsh near the foot of the tower. It is obvious that the gradual accumulation of deposit is not likely to check lively springs, possessing sufficient head to rise, hydrostatically, above the level of the alluvium; though in many cases they may lose themselves in the sandy strata.

I have not had an opportunity of ascertaining whether or not salt springs are known to exist in the marshes near the Forts, and above. I fully expect to find, however, that they do exist, though, for obvious reasons, they will become less and less abundant as we ascend the river. At New Orleans, as already stated, gas and salt water are reached, and brought to the surface with considerable vehemence, by bores varying from 31 to 56 feet;* and I have no difficulty in believing in the correctness of the impression made upon Col. Sidell, that the foundations of the New Orleans customhouse were located upon a mudlump.† That such obstinate resistance as that of the "Head of the Passes" to denudation can hardly be attributed to a mass of river deposit, I have already intimated. A large mudlump mass has, probably, first caused the deflection.

[To be continued.]

* See above, p. 245.

† Lyell's Principles of Geol., 10th ed., p. 552

Origin of the Mudlumps.—The causes which give rise to the formation of mudlumps have been to some extent discussed by Sidell, Thomassy, and Lyell (*loc. cit.*). The former is inclined to ascribe the upheaval *chiefly* to the pressure of gas formed in the decay of driftwood and the like, buried in the river deposits. Thomassy resorts to the hypothesis of the existence of subterraneous channels communicating with the river, or with equally hypothetical reservoirs of water, far above; while Lyell ascribes the bulging of the bottom to the pressure of newly formed deposits upon a substratum of yielding mud, accompanied, and aided incidentally only, by the evolution of marsh gas in the decay of organic matter. I myself, having become aware of the existence of a strong artesian water pressure in the littoral formations of the Gulf, was inclined to ascribe the origin of the upheaving force to that source; and my visit to the mouths had for its object mainly, the comparison of the facts with each of the three admissible hypotheses, that of Thomassy being too fanciful to be seriously entertained.

As already stated, I at once found that the evolution of gas in the active vents was too insignificant to be considered as the cause of the rising of the liquid mud, which so greatly exceeded it in bulk, that the ascensional force of the bubbles, especially in so wide a vent-tube, would be utterly inadequate to balance the downward tendency of so heavy a liquid. It might still be alleged, in favor of the gas-hypothesis, that its pressure might be exerted statically upon the surface of the mass of liquid mud covered by impervious strata; but it is obvious that in such a case, the gas itself, necessarily accumulating at the highest, and therefore weakest, points, of the superincumbent mass, would be much more likely to break through by itself, promptly exhausting its force and quantity at any one point. No such rushing outbreaks of gas have ever been recorded, save in the case of blowing up of a lump with gunpowder; and, as Lyell remarks, this view renders inexplicable the occurrence of lumps exclusively about the mouths of the passes.

The latter objection applies equally to the hypothesis of the artesian origin of mudlump force, unless upon the (unproved) supposition that the excavation of the river channel might have rendered the outbreak of the artesian water easier there than elsewhere. But instead of *excavating*, the Mississippi has for a long time past always thrown *shallows* in advance of its

mouths; and unless it were conclusively proven that *the matters ejected by the mud-springs* were such as could not originate in the present delta formation, the artesian hypothesis must lose all show of probability. An accurate investigation of the matters in question, solid, liquid, and gaseous, was therefore indicated. A few specimens for this purpose were collected for me by Mr. Marindin, in 1867; but the perusal of his report accompanying them convinced me that a personal examination *in loco* could alone insure a perfect certainty as to their significance, and accordingly, in the autumn of the same year, I re-collected specimens from the same, as well as from other localities. Very unfortunately, the arrangements for gas analysis at my command were so imperfect that, while waiting for their improvement, the gas specimens were so vitiated by diffusion through corks and wax as to render them useless; and I have been unable to replace them as yet, but hope to do so in the near future.

Mudlump Gases.—The examination of the water and mud seemed, however, most likely to conduce to a solution of the problem, at any rate; for after all, the only information which could be furnished by gas analysis would be to indicate, by the greater or less amount of carbonic acid present, whether the gas originated from matter comparatively fresh and in its first stage of decomposition, or had its source in materials far advanced toward the stage of lignite or coals. The only perfectly reliable determination made was that of the carbonic acid contained in the gas collected from the most easterly active cone on Marindin's Lump, Passe à l'Outre, the rest of the determinations being somewhat vitiated, though doubtless very nearly correct.* The result was as follows:

Gas from East Crater, Marindin's Lump, Passe à l' Outre.

Carbonic acid,	9·41
Marsh gas,	86·20
Nitrogen,	4·39
	100·00

Oxygen was not present.

The percentage of carbonic acid in this gas is very unusually large; its composition is nearest to that of the gas from common swamps, where vegetable matter is in its first stages of decay. The proportion between marsh gas and nitrogen is nearly the same as in the gas from the gas wells at New Orleans (see p. 245); but there is three times as much carbonic acid present

* After the explosion in the eudiometer, some nitrate of mercury was observed on its walls, in consequence of inadequate dilution of the gas. But the marsh gas was estimated from the carbonic acid absorbed after the explosion, the nitrogen by difference.

in the mud-lump gas, in accordance with the presumable more advanced stage of decay existing in the former locality.

Mudlump Spring Waters.—In taking specimens, common quart bottles were filled by immersion in the craters themselves, and immediately sealed. The liquid mud thus obtained would, after a while, separate into a lower stratum of pretty solid mud, and an upper one of clear water, in varying proportions. For analysis, the latter was carefully decanted, and the turbid part rapidly filtered through a Bunsen's pressure filter, and measured. 400 ccm. were then boiled to precipitate carbonates and silica, the filtrate re-diluted to the original bulk, and from 50 to 100 ccm. used in the determination, in separate portions, of chlorine, of lime and magnesia, and of sulphuric acid and alkalies, respectively; while a fourth portion served for an approximate determination of the solid residue, for the sake of roughly controlling the final results.*

I give below, in tabular form, the results of these analyses; presented in three different forms, for the sake of ready comparison with the composition of sea-water, from which they seem to be derived by a series of reactions easily understood from the nature and condition of the materials with which they are associated.

I. Water from the basin of a spring on a mudlump off Stake Island, Southwest Pass. Evolves gas and water in about equal proportions, no mud, but only fine sandy matter; and water flows off clear over the rim of the basin, which is two feet above tide level, and at the foot of a large extinct cone with a lagoon, surrounded by a high rim, in the center.

Water about $\frac{1}{4}$ of the bulk in bottle, the rest fine sand. Taste, very salty; color, slightly yellowish; turns brownish turbid very quickly on exposure to air. Coll. Dec. 3, 1867.

II. Water from a mudlump spring on Northeast Pass, collected by H. L. Marindin, of U. S. Coast Survey schr. Varina, in February, 1867.

According to the recollection of one of the crew, this specimen was taken from the same cone as the following one (No. III).

Water clear, faintly yellowish, about $\frac{1}{4}$ by bulk of the contents; the rest sandy mud. Turns turbid rapidly on exposure to air.

* With mixtures of this kind no method but that of evaporation with excess of carbonate of soda will yield anything more than an approximate estimate of the solid residue; involving an amount of labor and care not always justified by the end in view, when the relative amounts of ingredients can serve to control. The chlorine determination being the most accurate, and almost always in excess of the bases found available to form chlorides, the chloride of sodium, as here recorded, is the *calculated* amount, as is also the sum of ingredients.

Analyses of Waters from Mudlump Springs, Mississippi Passes.

	Southwest Pass. I.			Northeast Pass. Salt Spring Island. February. II.			Northeast Pass. Salt Spring Island. December. III.			Passe à l'Outre. Marindin's Lump. East Crater. IV.			Passe à l'Outre. Marindin's Lump. West Crater. V.		
	a.	b.	c.	a.	b.	c.	a.	b.	c.	a.	b.	c.	a.	b.	c.
Chloride of Sodium,	2·5374	80·060	81·662	2·7847	81·937	84·117	2·7751	82·809	84·670	1·2439	79·094	85·857	1·7544	79·708	84·055
" Potassium,	0·0280	0·884	0·901	0·0441	1·297	1·332	0·0441	1·316	1·346				0·0166	0·754	0·795
" Calcium,	0·0725	2·287	2·388	0·0342	1·006	1·033	0·0638	1·903	1·947	0·0018	0·114	0·124	0·0649	2·947	3·109
" Magnesium,	0·4635	14·624	14·917	0·4475	13·168	13·518	0·3945	11·773	12·037	0·1962	12·475	13·543	0·1259	11·440	12·061
Sulphate of Calcium,	0·0007	0·022	0·023							0·0069	0·439	0·476			
" Magnesium,															
Carbonate of Calcium,	0·0011	0.035		0·0313	0·921		0·0001	0·003		0·0695	4·419		0·0230	1·045	
" Magnesium,	0·0446	1.407		0·0447	1·315		0·0724	2·160		0·0392	2·492		0·0745	3·385	
" Iron,	0·0158	0.499		0·0121	0·356					0·0119	0·757		0·0128	0·582	
Silica,	0·0007	0.022					0·0012	0·036		0·0033	0·210		0·0030	0·139	
	3·1643	99·840	99·891	3·3986	100 000	100·000	3·3512	100·000	100·000	1·5727	100·000	100·000	2·2010	0·06100	100·000
Specific Gravity,		1·02388			1·0244						1·01196			1·01689	

a. Ingredients in 100 ccm. of the water. b. Ingredients in 100 parts of solid residue. c. Ingredients in 100 parts of solid residue exclusive of carbonates and silica.

TABLE—*continued.*

	Knight's Gas Well. New Orleans. VI.			Gulf Water. 30 miles out. VII.		Sea Water. Average composition. VIII.	
	a.	b.	c.	a.	b.	a.	b.
Chloride of sodium,	0·02310	37·880	56·479	1·6723	76·870	2·700	77·032
" potassium,	0·00790	12·950	19·315	0·0357	1·640	0·070	1·997
" calcium,	0·00060	0·980	1 467				
" magnesium,	0·00630	10·330	15·404	0·2310	10·620		10·271
Sulphate of calcium,							
						0·360	
Bromide of magnesium,				trace.	trace.	0·002	0·058
Sulphate "	0·00300	4·920	7·335	0·1077	4·950	0·140	3·994
				0·1289	5·920	0·230	6·562
Carbonate of calcium,	0·01120	18·360				0·003	0·086
" magnesium,	0·00760	12 450					
" iron,							
Silica,	0·00130	2·130					
	0·06100	100·000	100·000	2·1756	100·000	3·505	100·000
Specific gravity,				1·01630		1·0298	

III. Water from faintly active cone on Salt Spring Island, off Northeast Pass; from crater on west side of island, about ten feet above sea-level. Collected Dec. 2, 1867.

Water very salty, about $\frac{3}{4}$ of the whole mass; the rest, a somewhat sandy mud; color, slightly yellowish; turns turbid rapidly on exposure to air.

The larger proportion of water in this specimen, as compared with the preceding, doubtless results from the comparative inactivity of the cone, as compared to that at the time of high water in February. The same fact may account for some of the difference in composition.

IV. Water from East Crater on Marindin's Lump, Passe à l'Outre. See p. 362. Collected Dec. 2, 1867.

Forms about $\frac{3}{5}$ of the bulk in the bottle, the rest is soft clayey mud. Faintly brownish, clear; becomes brownish turbid rapidly on exposure to air.

V. Water from West Crater on Marindin's Lump, Passe à l'Outre; same date.

Water about $\frac{1}{4}$ of bulk in bottle, the rest clayey mud. Not very salty; colorless, but turns turbid quickly on exposure to air.

VI. Water from gas well bored by J. B. Knight, at New Orleans. Clear, with a little sand at bottom; taste, faintly brackish.

VII. Water of the Gulf of Mexico, taken from surface 30 miles out, southeast from Southwest Pass, Dec. 1867.

VIII. Average composition of sea-water, according to Regnault.

The general results deducible from the above analyses may be thus stated:

1. There is a general similarity of composition between the waters of the mudlump springs, indicating their derivation from a common source of supply. But springs on the same lump, as well as the same spring at different times or stages of water, may vary quite sensibly, both in composition and concentration. Their density is generally inferior to that of sea-water, though at times approaching it closely.

2. There is an obvious approximation of the ratio between the two chief bases—sodium and magnesium—to that existing in sea-water; the variations being no greater than are observed in sea-water from different localities.

3. The most obvious difference is the absence of sulphates, and their partial replacement by chlorides; also

4. The presence of large amounts of the carbonates of the earths, as well as of iron, dissolved in carbonic acid.

5. The amount of potassium salts is decidedly diminished.

6. Bromids appear to be entirely absent, and are present in traces only, in the water of the Gulf itself.

It is stated that the waters of some of the springs are fresh. I have found all brackish *at least*, and as the population of the delta is much in the habit of drinking water of questionable freshness, their judgment in the matter may not be the most reliable.

As regards the water of the New Orleans well, though at first sight it differs materially from the others, it will be observed that when in C, potassium and sodium chlorides are classed together, its composition becomes not unlike the mudlump waters. Its great dilution accounts for the excessive proportion of carbonates.

The Gulf water approaches very closely in its composition to the normal one of sea-water, as given by Regnault.

Mud from Mudlump Springs.—I have already stated, that the stratified material of the mudlumps (whether formed by the action of mud springs, or bodily upheaved) is free from visible shells or other fossils, save particles of woody matter; while the amorphous material which forms the surface and generally also the beach, often abounds in such organic remains as are now usually washed ashore, having manifestly been *cast* up and imbedded in the mud by the waves.

I have examined microscopically the mud remaining in the specimen bottles after decanting the water for analysis; they were immediately refilled with distilled water, and kept closely stopped until examined. I give below the record of examination of the mud, corresponding to analysis No. V, from West Crater on Marindin's Lump. Two or three others similarly examined gave a like result.

A sample from the general mass shows it to consist mainly of very fine quartz sand, mostly angular, with but a few large, angular grains; and but little true clay.

In washing the mass, even the first washings were found to contain but little clay, but chiefly very fine suspended silex. A few ill defined spicules, a Navicula, and bark fibers.

In the middle portion, spicules a little more abundant.

In the coarsest portion, much variously colored mica, along with, mostly sharply angular, quartz grains; numerous particles of water-browned wood; very distinct spine of a radiate; several specimens of Rotalina, and fragments of same as well as Uvigerina, Cristellaria, Amphistegina, and Coccineis? Also iridescent fragments, showing lines of growth, from the edges of larger bivalves.

Quartz grains mostly transparent and angular; some of milky, oil-green, and rose quartz; these mostly rounded. This sand resembles closely that of the bottom outside Northeast Pass bar, in 40 to 50 feet water; specimens of which were furnished me by the Coast Survey party, under command of Capt. F. V. Webber of the schooner Varina, in 1869.

Specimens from mudlumps on Southwest Pass show coarser sand, and rather more Foraminifera.

The character of the materials ejected by the mudlump springs, as determined by the foregoing investigations, may be summed up as follows:

1. The *gas* is such as is evolved by vegetable matter in its *first* stages of decay or lignitization.

2. The *earthy matter* contains both river and marine fossils—driftwood reduced almost to its cell-elements by maceration and trituration, as well as Foraminifera. Its fineness is such that, before final deposition, it may have been carried out into water of considerable depth.

3. The mudlump waters appear to be sea-water more or less diluted, and chemically changed under the joint influence of fermenting organic matter, and the more active ingredients of the river deposit, viz: carbonates of lime and magnesia, and oxide of iron.

The first effect thus produced would probably be the addition of the soluble carbonates of these metals to the solution. But the soluble sulphates could not, in the presence of a soluble iron salt, long resist the reducing influence of decaying organic matter. As usual under such circumstances,* iron pyrites would be formed, withdrawing in the end all the sulphuric acid from the solution, and forming, instead, equivalent amounts of the respective carbonates. The amounts of the chlorides of

* See Bischoff, Chemische Geologie, vol. i, p. 559.

sodium and magnesium originally present would thus, also, be relatively increased; and this again tallies with the analytical results. Yet while the proportion between these bases is maintained* the actual *replacement* of sulphate of magnesium by the chloride constitutes a change not readily explained. At first sight it would seem that the excess of chlorine belonging to the chlorides of calcium and magnesium must be an outside accession; but our knowledge of the mutual reactions between the substances here present under strong pressure, is perhaps too fragmentary to justify an assertion on this point.

The diminution of the potash salts is doubtless referable to their absorption by the clays present, in preference to all other compounds. The filtration of sea-water through soil would, according to Liebig's experiments, produce a like result.

Conclusions.—In view of the foregoing facts, the explanation of mudlump phenomena suggested, substantially, by Sir Chas. Lyell, seems the only tenable one; it requires, however, some modification as regards the mass supposed to exert the pressure, and some corollaries as to the mode of action.

I have before suggested, that the rapid protrusion of the mouths of the river into the Gulf, in advance of the body of the delta, is owing to the shelf of "blue clay bottom" extending, at a comparatively slight depth below the sea-level, and with a gentle slope, far out into the Gulf. It is upon this impervious clay that the present bars are based; and upon it, in advance of the bar, will be deposited the finest of the river mud, at a depth at which, perhaps, the sea-water is at the time quite undiluted, and fully adapted to marine life; which will therefore deposit its vestiges in it, associated with the finest particles of driftwood, etc. Mud thus deposited may remain unconsolidated for a great length of time, unless the water be drained off or through it by some means.

The bar, in its annual advance of about 338 feet, will cover over this liquid mud stratum, exerting a pressure much greater than that of the sea; and were it resting on a pervious bottom, the liquid mud would doubtless soon be consolidated into a sheet of clay. As it is, the tendency will be to squeeze it from under the crest of the bar, both seaward and landward. The very gradual seaward slope of the bar will render the movement in that direction a very slow one, under a greater depth of water and heavy frictional resistence. Not so on the land side, where, as the bar advances, the superincumbent pressure is measurably relieved by the erosion of a channel by the

* The ratio is for

Atlantic sea-water,	30·5 : 3·0	Marindin's Lump water,	30·5 : 2·8 (min.)
German Ocean water,	30·5 : 4·0	Southwest Mudlump,	30·5 : 3·56 (max.)
Average sea "	30·5 : 3·4	Average of those analyzed,	30·5 : 3·1

current, which, especially in flood time, carries much of the bottom deposit bodily over the bar and drops it to seaward.* At weak points of the bottom inside the bar, therefore, the upward pressure of the mud may cause a bulging up at least to the level of the bar-crest, and, perhaps, taking into account the difference in the specific gravities of the comparatively solid bar and liquid mud, even as far as the surface of the water. But this, considering the question as coming within the domain of liquid statics, would seem to be about the extreme limit to which the bottom itself could be brought up.

I have found the specific gravity of the mud flowing from the West Crater on Marindin's Lump, to be about 1·25; that from the cone on Salt Spring Island, on Northeast Pass, 1·30; while that of bar deposit from the crest of the Northeast bar, wet as brought up by the lead, was 1·75. The heights of communicating columns of these substances, if sensibly liquid, should be as 5 to 7; but this ratio could apply, in the case of upheaval, only so far as the *difference* of level between the bar and the upheaved bottom is concerned, since the latter must be presumed to be similar to the bar in its materials and structure. Should the current, however, continue to denude the crest of the upheaved mass, the rising would continue and the semi-fluid mud might finally break through, forming a mudspring, the height of whose vent above its source might finally increase to the extent corresponding to the difference of specific gravity.

The craters of mudlumps have been sounded to the depth of 24 feet, but no precautions were used to insure reaching the actual maximum depth. In the borings made for the foundation of a lighthouse on the Southwest Pass, by Mr. A. Palms (the record of which was courteously forwarded to me by the Engineer Dept.), a stratum so soft that the augur sank in it by its own weight, was met with at 58 ft., after striking, at 56 ft. a stream of water which "filled the pipe."

If then, the mud stratum, lying, say 60 ft., below the surface, be pressed by a column of deposit of 1·75 sp. gr., mud of sp. gr. 1·25 could thereby be raised 24 feet above the top of the pressing column; and this, considering the average depth of water on the bar, would account for the greatest heights to which cones are built up off the mouths.

But this is a close calculation, even if the data upon which it is based be deemed admissible in the form I have given them; and the frequency and energy with which the upheaving force acts, coupled with the fact that when a mudlump rises in the channel, so far from suffering denudation to the extent required for the breaking through of the mud, it more generally causes a silting up of the channel: seems to me to indicate that

* Humphreys and Abbot's Rept., p. 446.

a stronger force, less delicately balanced than the equilibrium of the bar, is "at the bottom" of the whole phenomenon.

This force, I think, is to be sought in the constantly increasing weight of the alluvial area above the mouths, which, itself possessing a series of mudlump vents at one time, must yet be resting in a great measure upon the still unexhausted mud stratum; as is proven by the existence of active lumps in the marshes, even though the increased resistance of superincumbent deposit as well as matted vegetation must render their occurrence there a rarity. There must still be a communication of liquid pressure between the older and newer portions of the modern delta; and this point is especially strengthened by the fact that a high stage of water in the river, which does not sensibly affect the depth on the bars, yet exerts a decided influence on mudlump activity. The river not only overflows the marshes, but loads them with additional sediment; and doubtless the increased hydrostatic pressure stops many a vent of gas, mud or water, which ordinarily discharges into the river's bed.*

Morgan's Lump, in the marsh of Southwest Pass, and Marindin's Lump on Passe à l'Outre, are now known to have been in undiminished activity for twenty-five years at least. Since that time the bars have moved gulfward a mile and a half; and one would think that, if the activity of the cones depended upon them alone, a notable difference ought to have been observed. But if the main force is a *vis à tergo*, while the bar serves mainly to prevent the escape of the mud to seaward, there is good cause for the secular persistence of vents that have escaped mechanical obstruction.

How far above the present mouths the head of pressure may extend, I do not pretend to conjecture. The borings at New Orleans seem to indicate that the mud stratum originally existed there also, but it would be extravagant to suppose that such pressure as that exerted in the gas wells of that city, could now be felt a hundred miles below. Yet it seems not at all unlikely, that the weight which steadily forces up the liquid mud to the top of Morgan's Lump, seven miles above the mouth, may, in part, be furnished by the enormous mass of vegetation which annually develops in the marshes, willow battures, and perhaps even cypress swamps above. Nor is the effect of gaseous pressure resulting from the constantly progressing decay of organic matter to be overlooked, although I doubt that this cause plays, ordinarily, anything more than a very subordinate part.

* I give on the plate (page 358) an ideal section, illustrating this explanation of the "origin of mudlumps."

Future observations, systematically carried out, will doubtless solve a good many of the questions here mooted; and though they may not lead to the suggestion of any means whereby the "evil geniuses of the Passes" may at present be conjured, a more precise knowledge of data, as well as of the statics and dynamics of *mud*, may enable us to predict at what point of advance of the mouths into the deeper water of the Gulf, their formation must cease. The Southwest Pass appears to be nearest that consummation devoutly to be wished; and were the closing of the other outlets practicable, the advance of the Southwest bar might become so rapid, as to let the youngest of the living generation witness a diminution of mudlump upheaval. Ultimately, the mouth might thus become similar to those of the Orinoco and Amazon; but until then, ceaseless activity of the river in the formation of bars and mudlumps must, in the interest of navigation and commerce, be met by an equally ceaseless and diligent effort for their removal from the channel. For while a concentration of the river current might possibly be made to maintain the needful depth upon the bars, its utmost erosive energy will be powerless against the tough, inert masses of the mudlumps.